Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: Feasibility Test of Terahertz Wireless Communications at 300 GHz
Date Submitted: 8 November 2010
Source: Ho-Jin Song, NTT Microsystem Integration Labs.
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Abstract: We present preliminary experiment results of terahertz wireless link at 300 GHz and discuss the feasibility of the terahertz waves for used in multi-Giga bps short range wireless communications systems.

Purpose: for discussion

Feasibility Test of Terahertz Wireless Communications at 300 GHz

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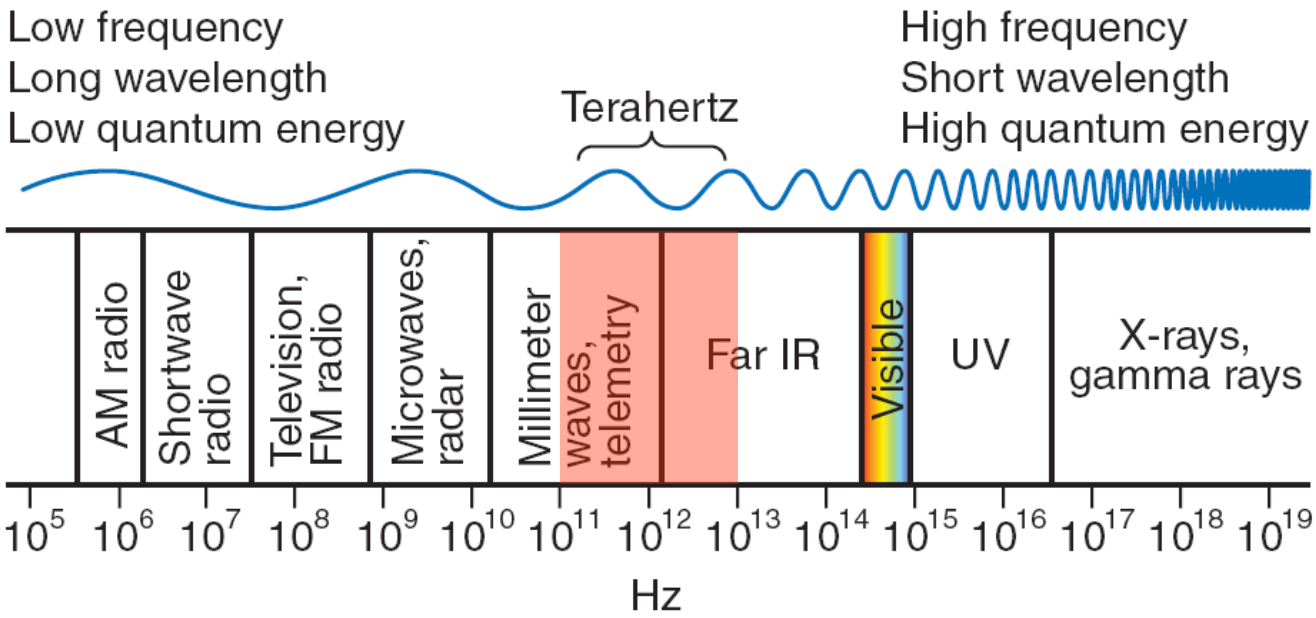
[1]NTT Microsystem Integration Laboratories.
[2]Osaka University

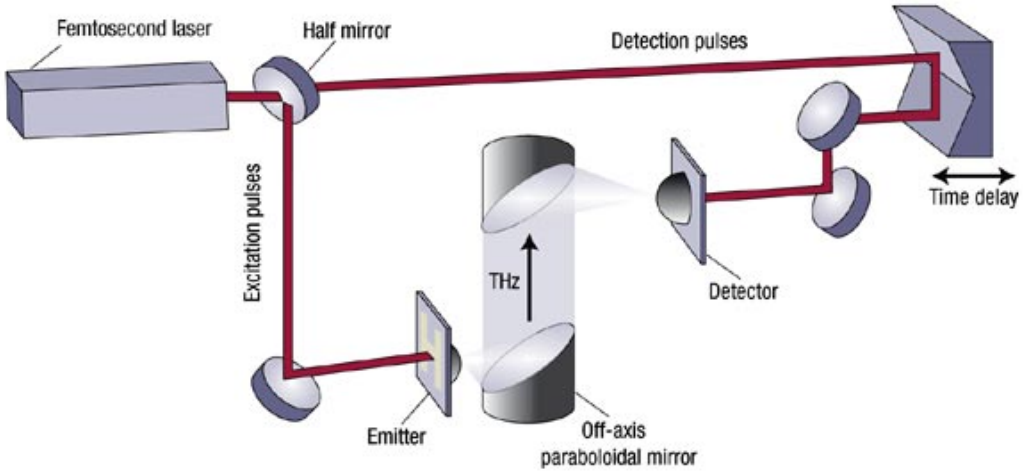
Terahertz Waves

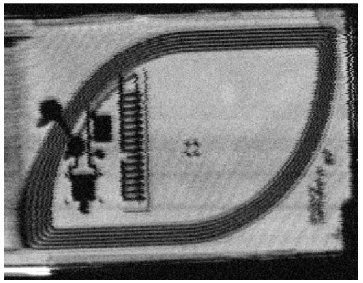


- Unique interaction pattern with molecules
- Capable of penetrating many non-metallic materials
- Short wavelength (compared to microwaves)

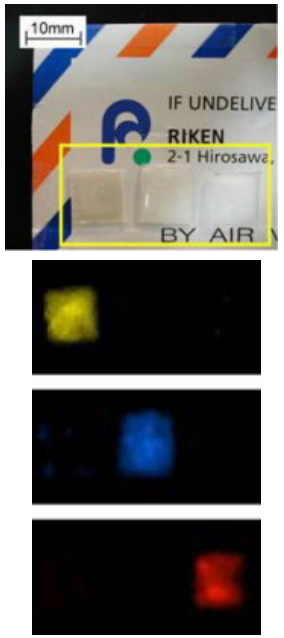
→ Sensing, imaging, security

Imaging for Security or Sensing

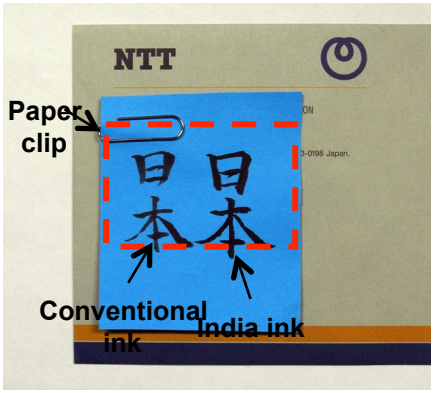


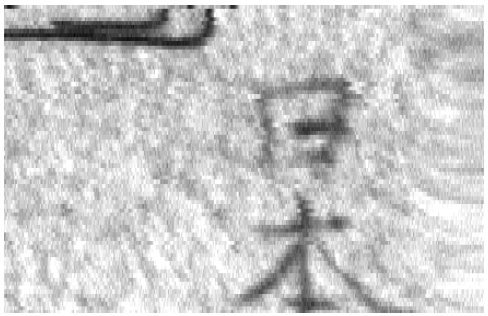


NTT, Japan



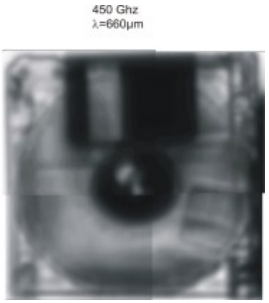
Nagoya Univ. Japan





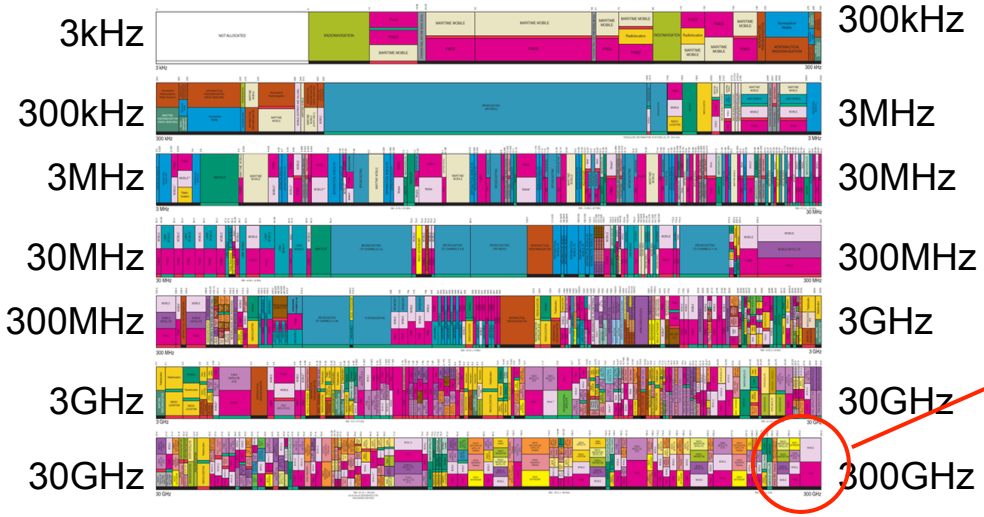
NTT, Japan

Jefferson Labs., USA

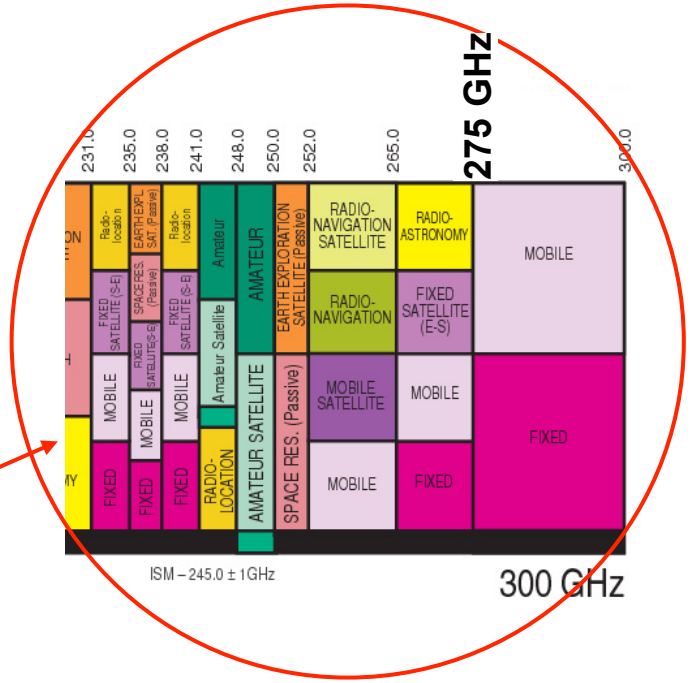


THz Waves for Communications

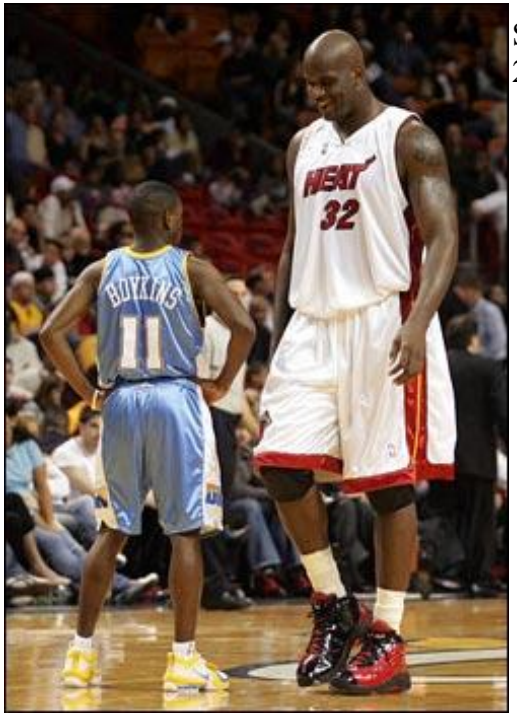
- **Large bandwidth**
  - For 300 GHz, BW is approximately 150 times larger than for 3G/4G cellular system (1.9~2.1GHz)
  - 150 times **larger data capacity** (more than 10 Gbps)
  - Or much simpler system
- **No one uses these frequencies !!**



U.S. Frequency Allocation Table



Natural Gift: Bandwidth or Height



Shaquille O'neal
2m 13 cm

Yao Ming
2m 28 cm

- Giant player is always attractive to NBA.
  - Height can't be earned by practice.
- So do THz-wave and its' bandwidth for communications.

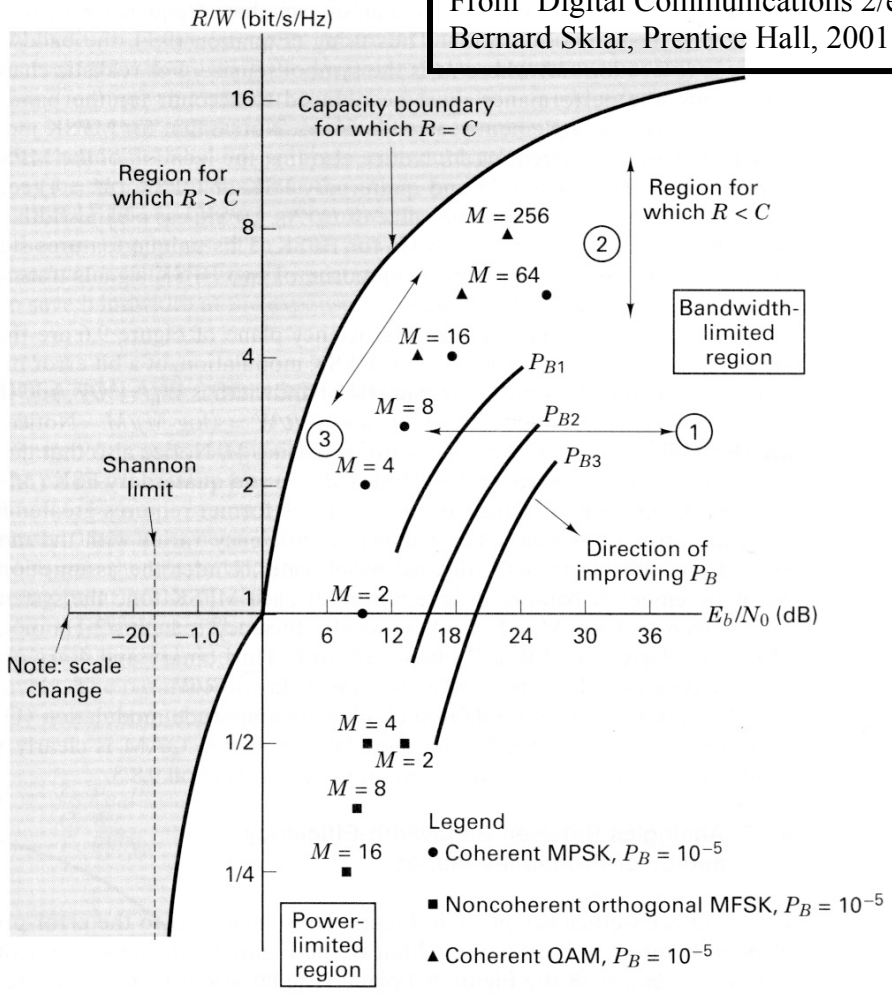
Shannon Limit

$$R \le W \log_2(1 + \frac{S}{N_0 W})$$

Maximum capacity relies on signal Power and Bandwidth.

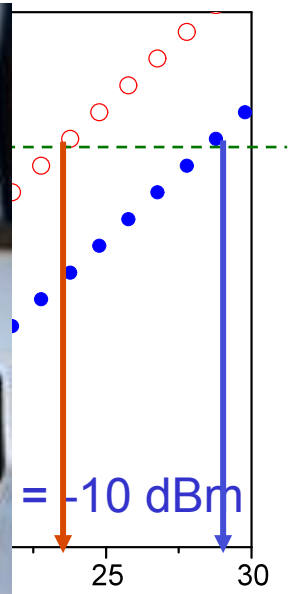
→ Large BW can compensate for lack of power.

From 'Digital Communications 2/e' Bernard Sklar, Prentice Hall, 2001



Is It Possible ?

Frequency (GHz)
Distance (m)
Spectral efficiency (b Hz)
Radiated power (dB
Noise level (dBm/Hz
Noise figure (dB)
Loss in Air (dB/Km)



x/Rx(dBi)

- 1-mW out romise us 10-Gbp
- In terahertz wave bands, 25-dBi antenna is small enough.

But,

NBA is NBA,

and

Theory is just theory.

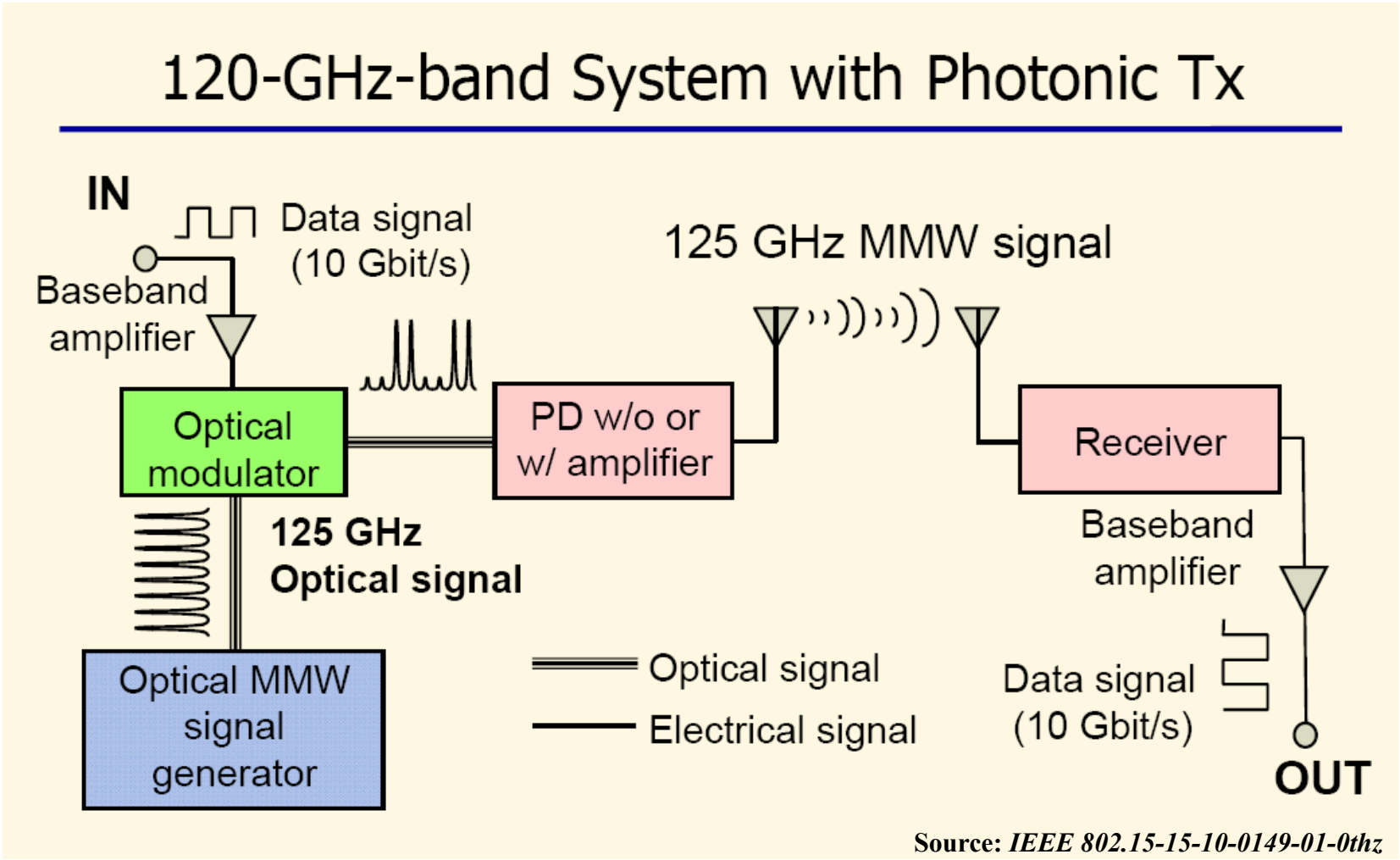
Show me some experimental results !

Feasibility Test

We need

- Transmitter
  - THz signal generator
  - Data modulation
- Receiver
  - THz Signal detector
  - Demodulator

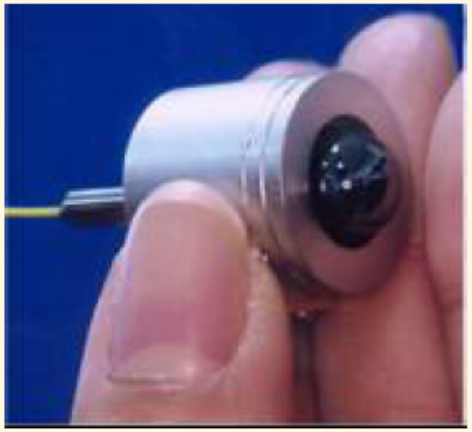
10 Years Ago in NTT



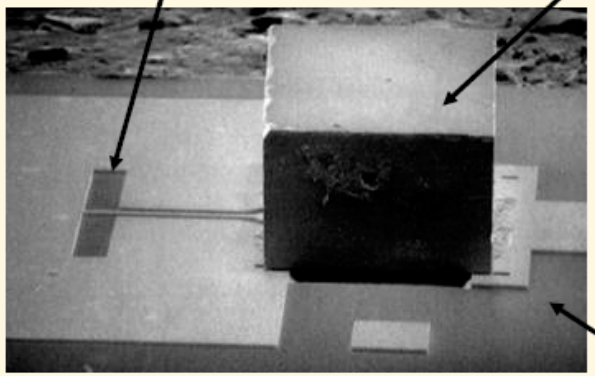
Source: ***IEEE 802.15-15-10-0149-01-0thz***

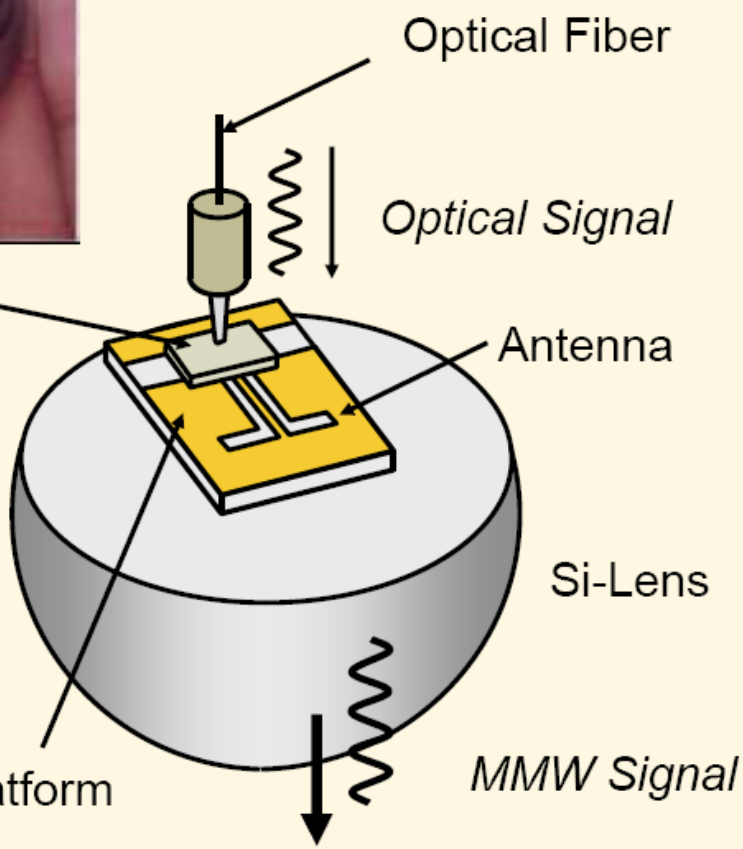
120-GHz Emitter

Source: *IEEE 802.15-15-10-0149-01-0thz*

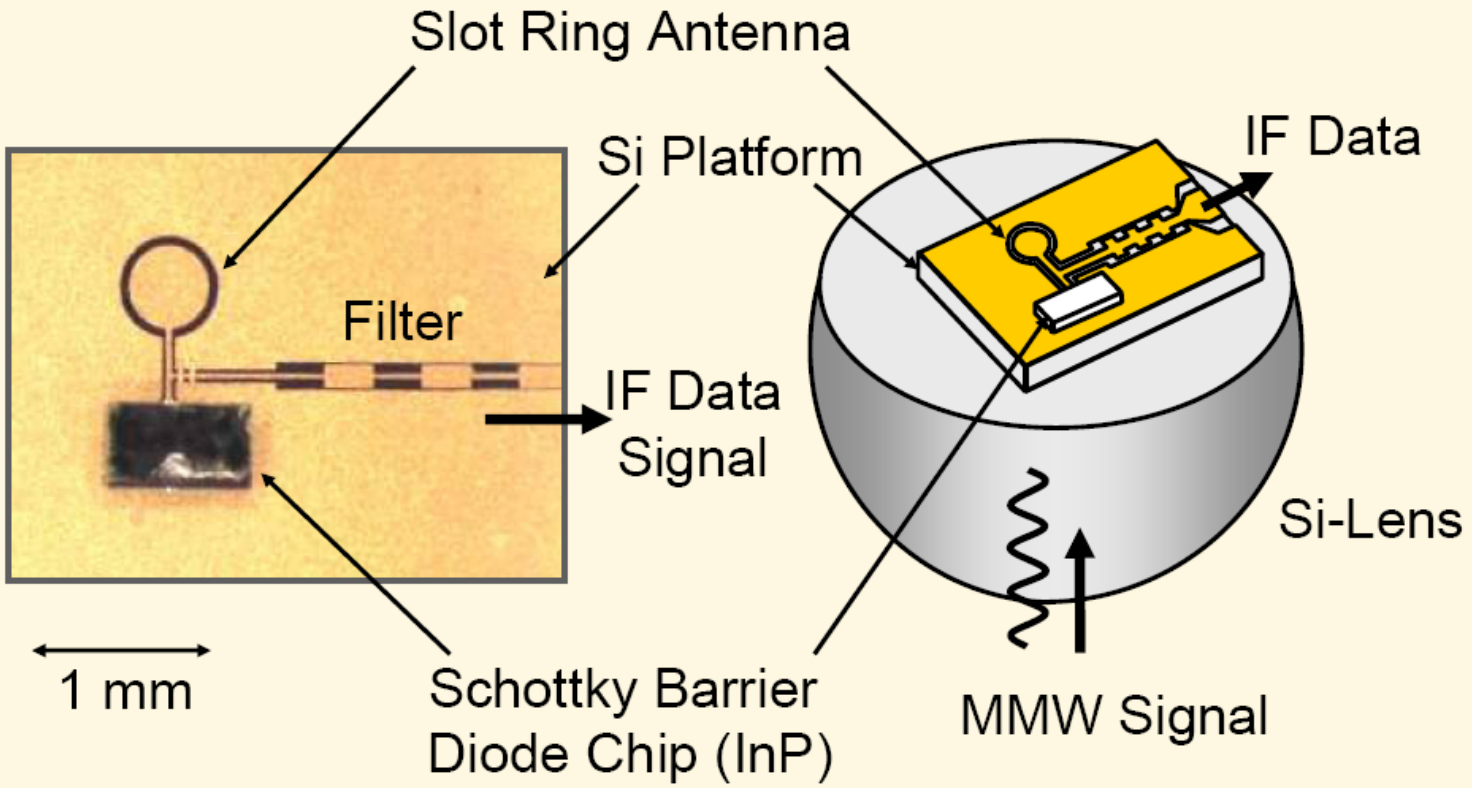


Microwave Photonics 2000





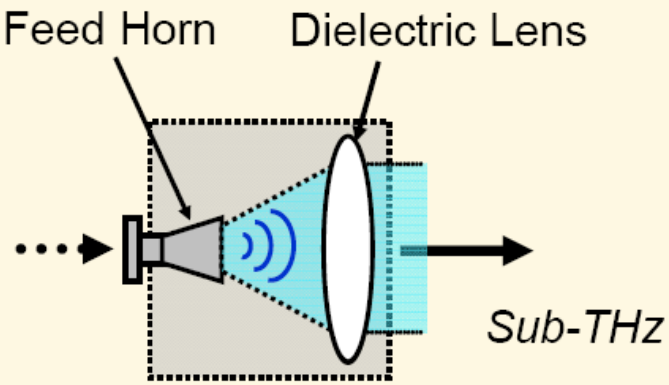
120-GHz Receiver for 10-Gbit/s

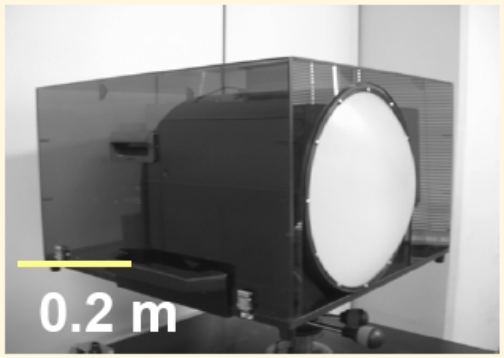


Source: ***IEEE 802.15-15-10-0149-01-0thz***

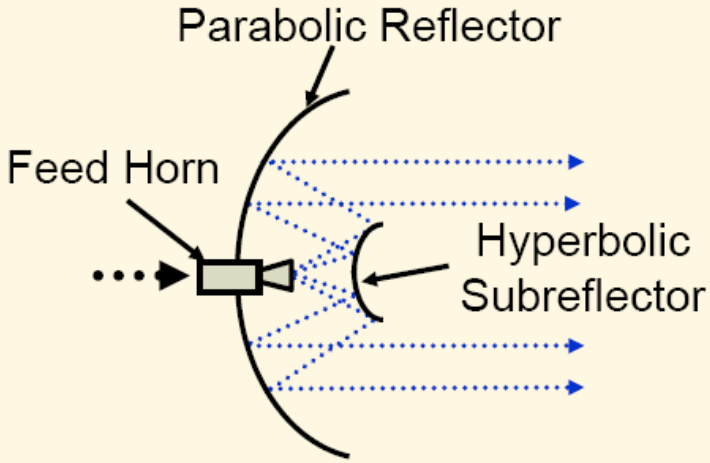
Antennas for Long Distance Link

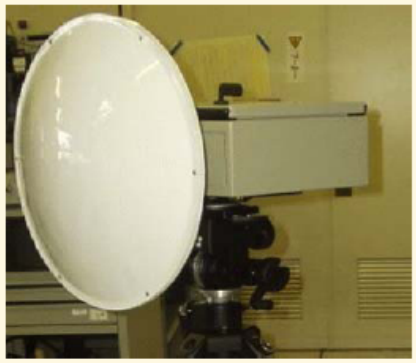
Lens Antenna





Cassegrain Antenna



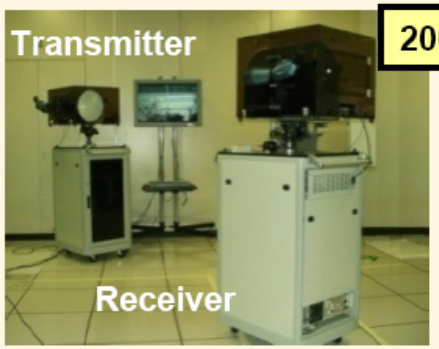


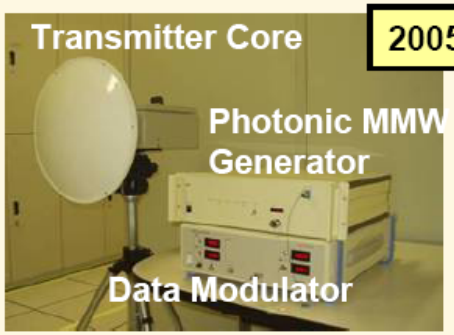
Source: ***IEEE 802.15-15-10-0149-01-0thz***

Hardware Evolution in 10 years

Photonics-based Transmitter

Source: *IEEE 802.15-15-10-0149-01-0thz*





- Output power: 10 mW, ~2 km
- Power consumption: 600W

Electronics-based Transmitter

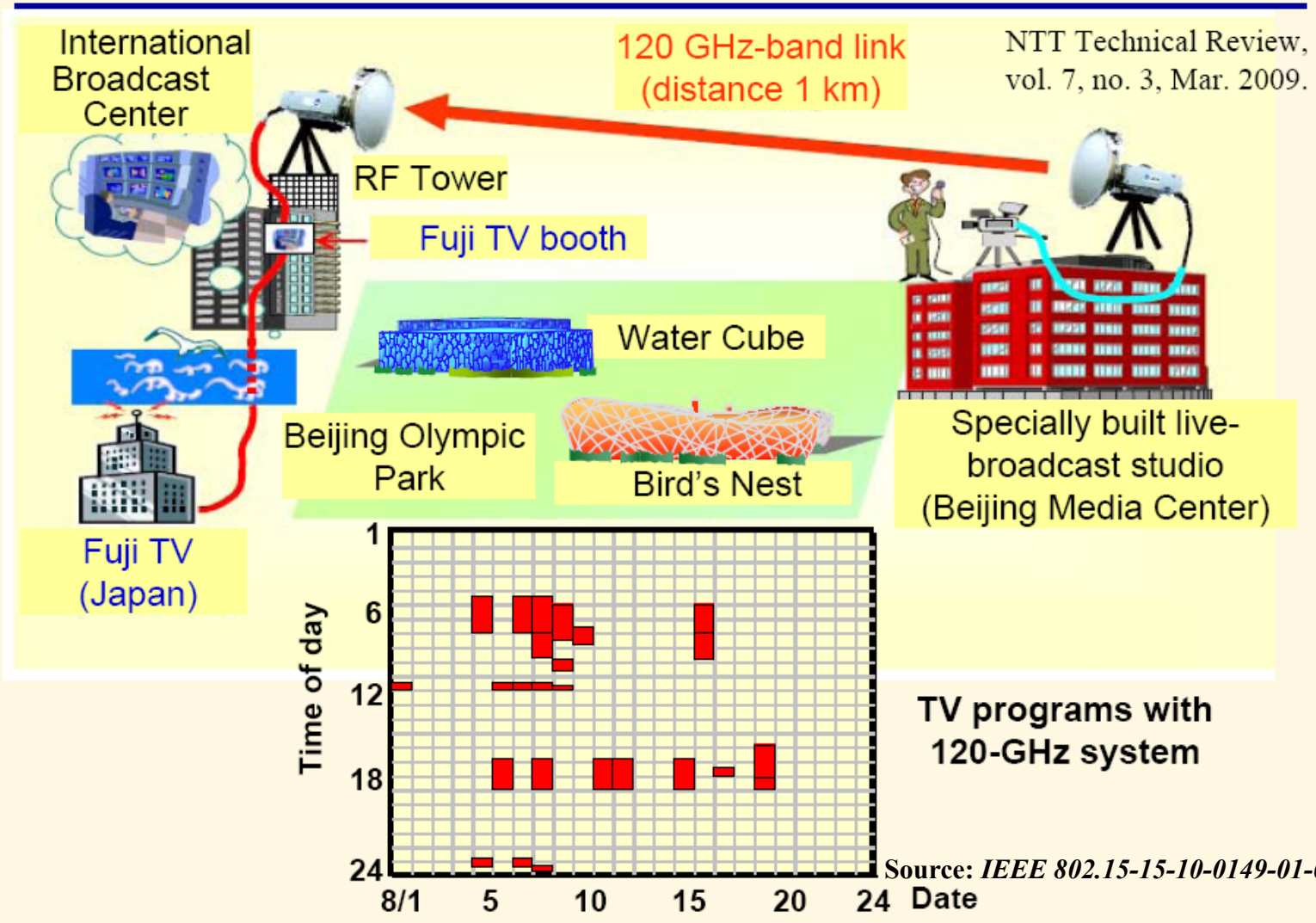
Volume: 1/6
Weight: 1/2

- Output power: 10 mW, 2.2 km
- Power consumption: 60 W

Easy set-up system

(NTT Technical Review, vol. 7, no. 3, Mar. 2009)

Trials at Olympics: Configuration



Source: *IEEE 802.15-15-10-0149-01-0thz*

Same Approach at THz Waves

But,

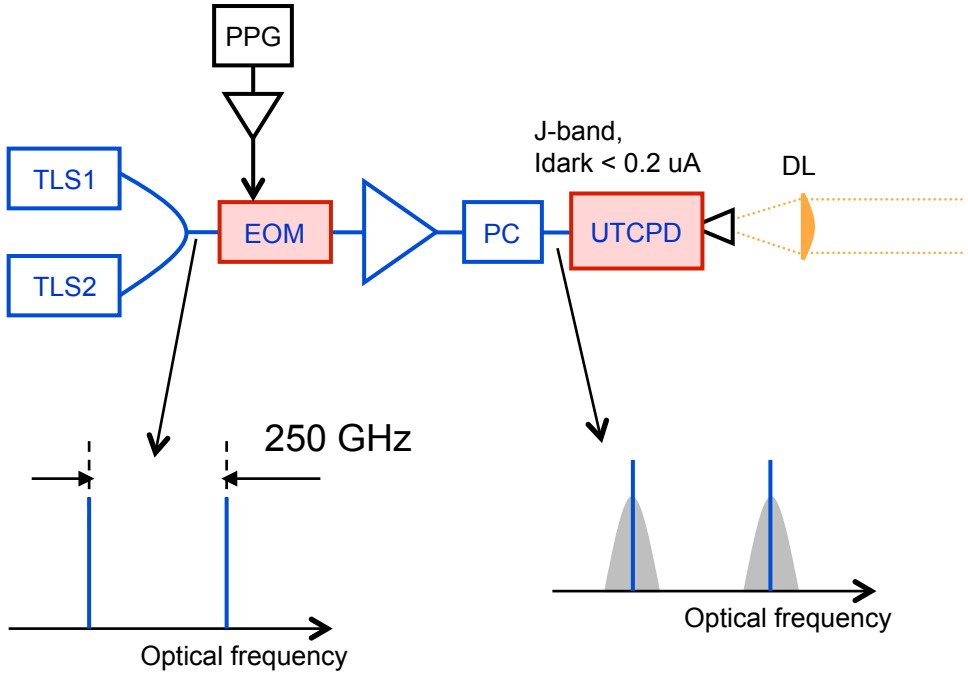
Short range applications

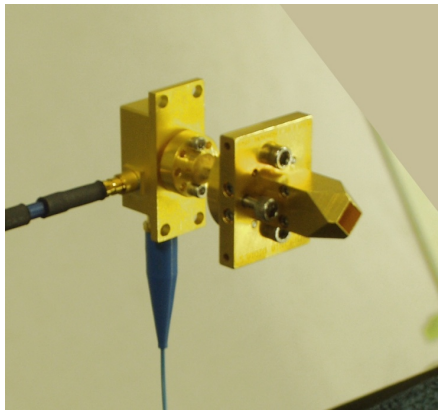
Possible Application

KIOSK data download
Via fiber-network

In Cabin link

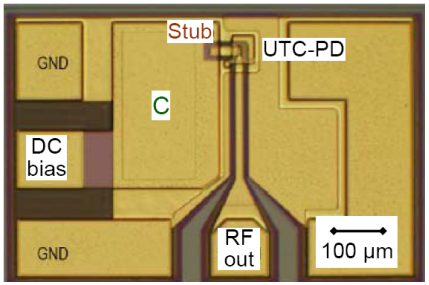
Transmitter: Photonics tech.

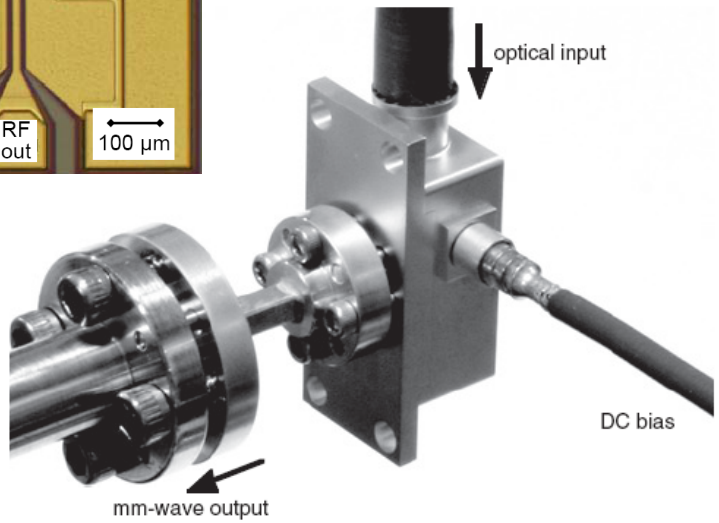


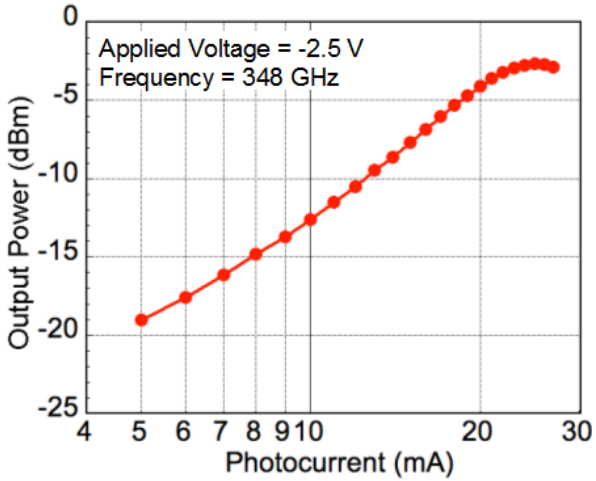


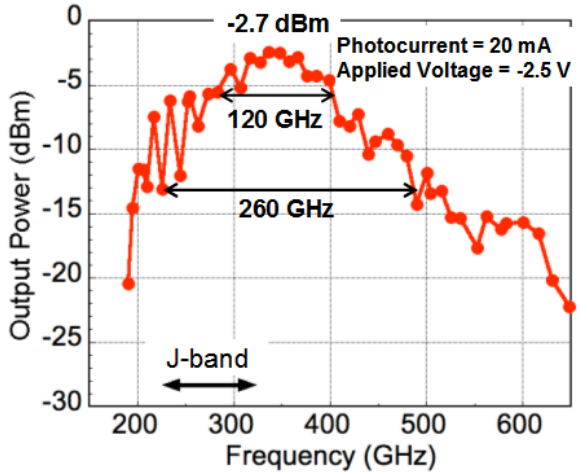
- Easy to handle large data rates up to 40 Gbps
- Easy to generate THz wave signal
- Possible to integrate with optical network → ROF ?

THz Operation of UTC-PD





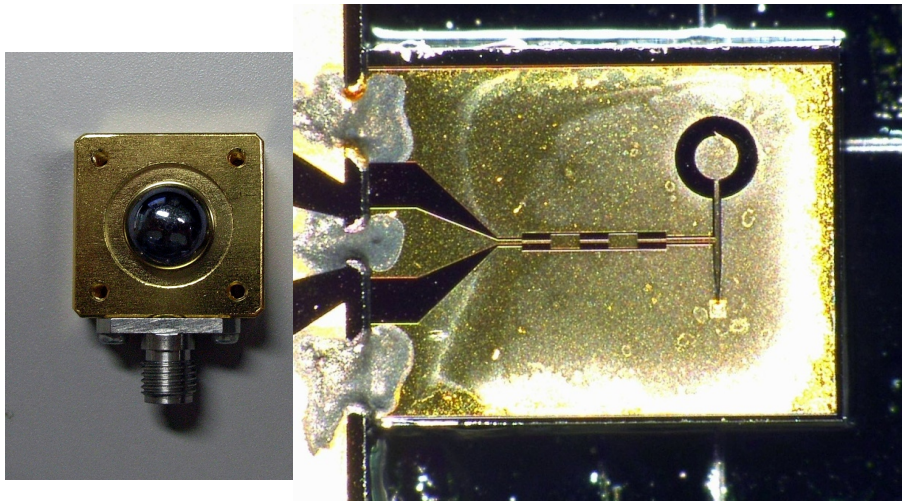




- Max. output : -2.7 dBm (350 GHz)
- Waveguide packaging

Receiver: Schottky Barrier Diode Detector

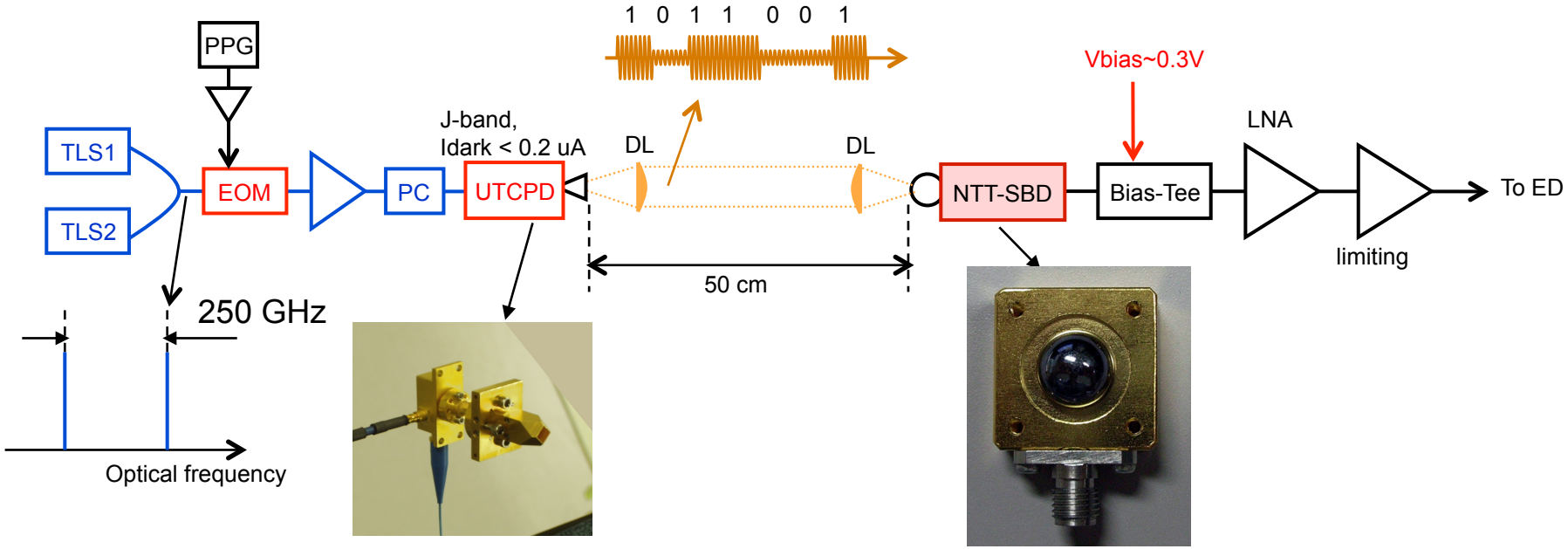
NTT developed



Commercial device

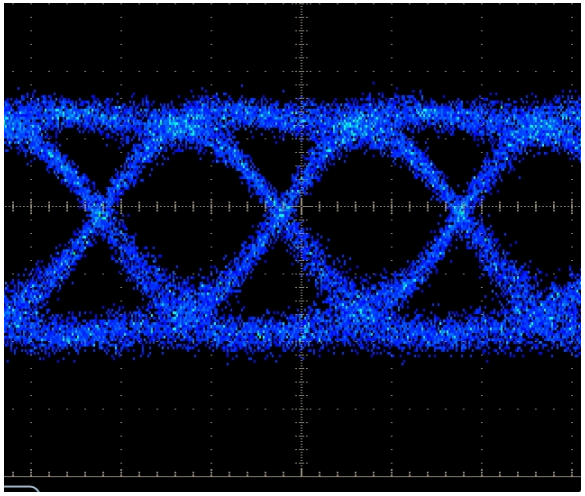
- Schottky barrier diode detectors as envelop detector for ASK signal.
- Commercial device showed better sensitivity and responsivity.
- But, both devices exhibited much worse noise performance assumed in the calculation.

First Trial at 250 GHz

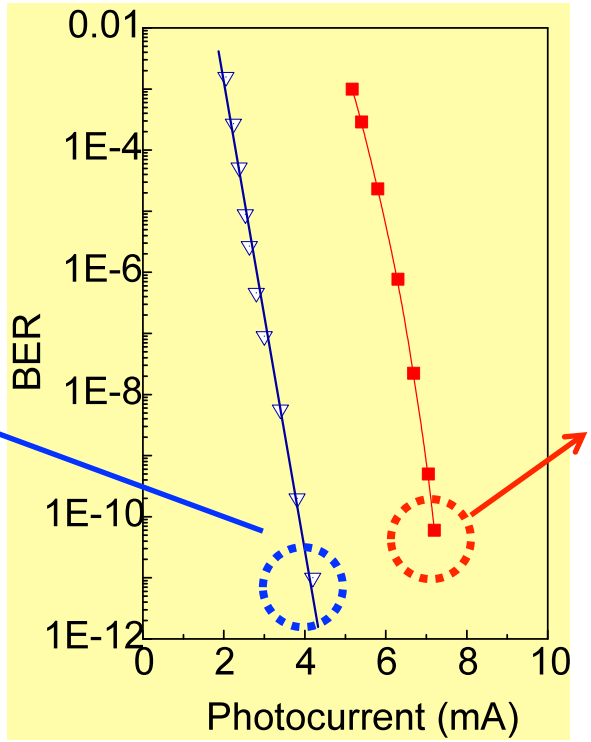


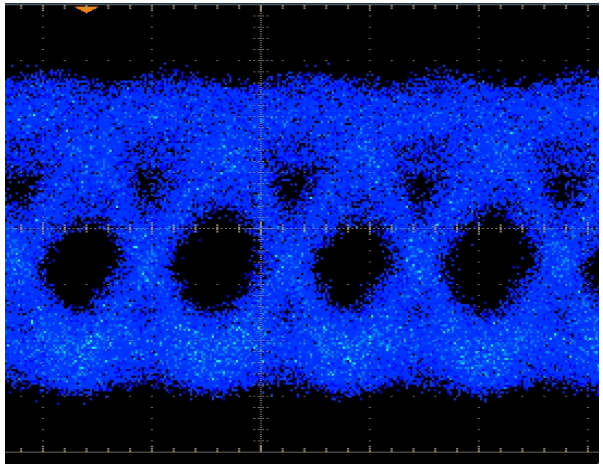
- Photonic transmitter + SBD detector receiver
- ASK modulation over 50-cm long distance
- No amplifier, but dielectric lens for both Tx/Rx
- Why 250 GHz? → limited performance of SBD

First Trial at 250 GHz



2 Gbps with
commercial detector
(P_{TX} < 10 uW)



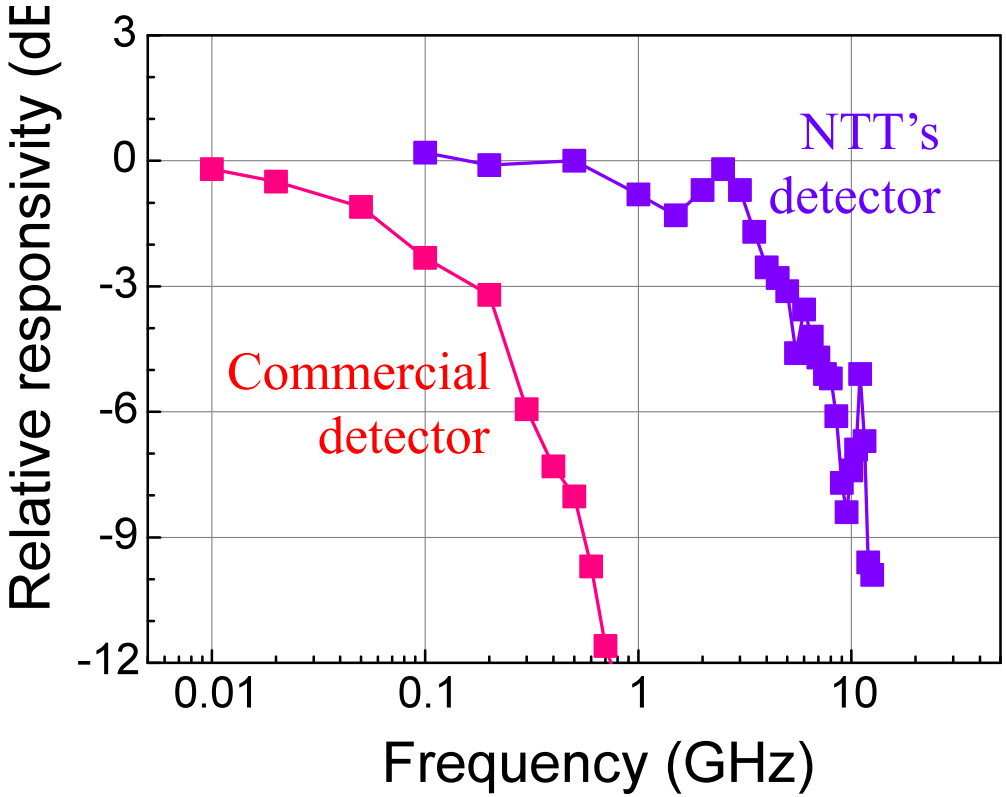


8 Gbps with
NTT's detector
(P_{TX} ~ 10 uW)

Electronics Letters 45(22)
pp. 1121-1122, 2009

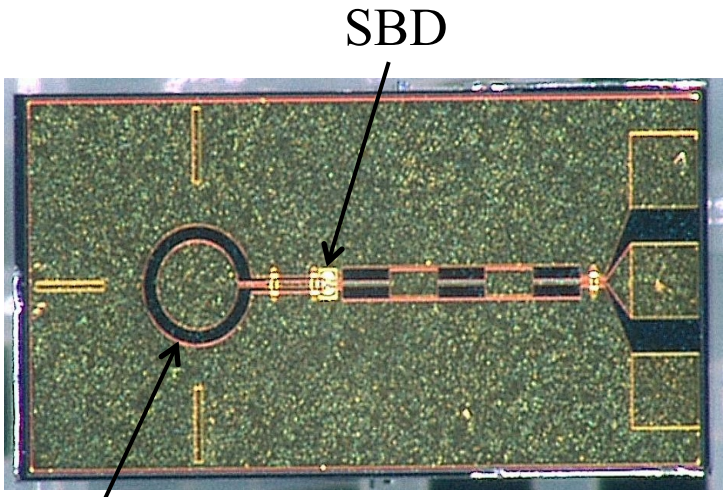
- We had enough power margin
  - UTC-PD can be driven up to 20 mA
  - Error free transmission up to 3-m distance
- NTT device provided higher data rate

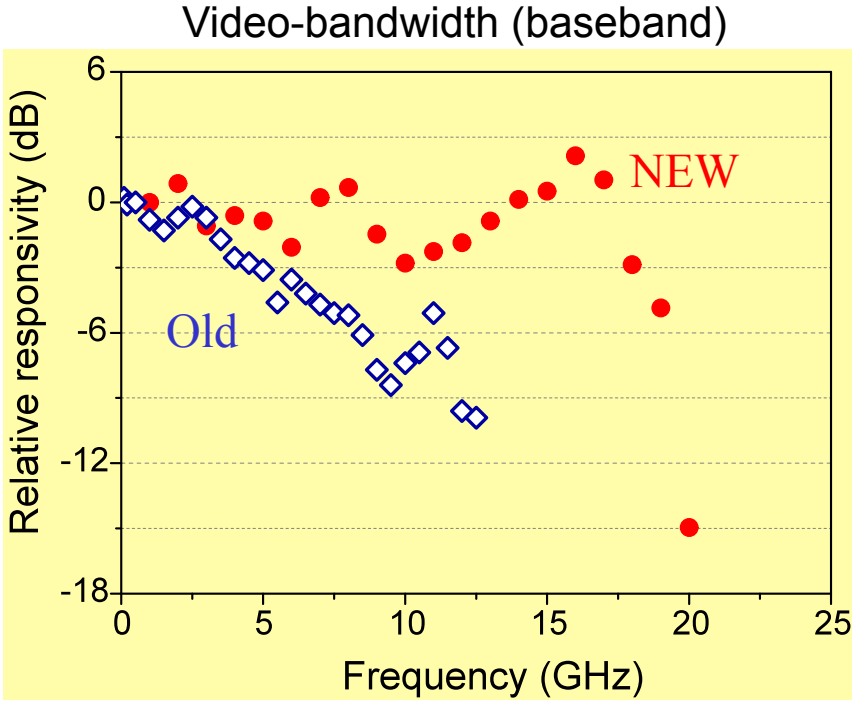
Problem Was Bandwidth



- Video bandwidth (baseband output bandwidth) of detectors limit data capacity

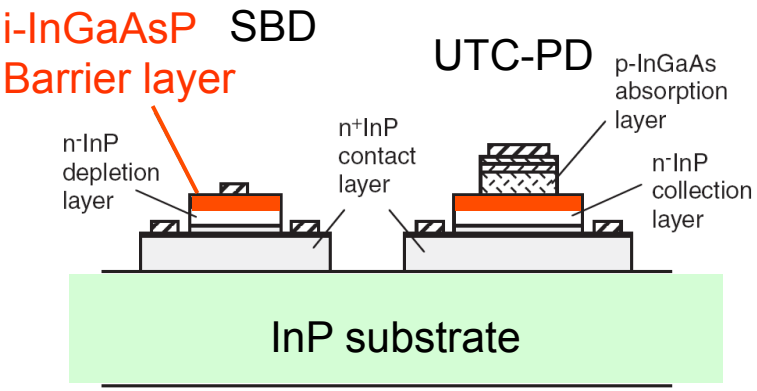
NEW Schottky Barrier Diode Detector

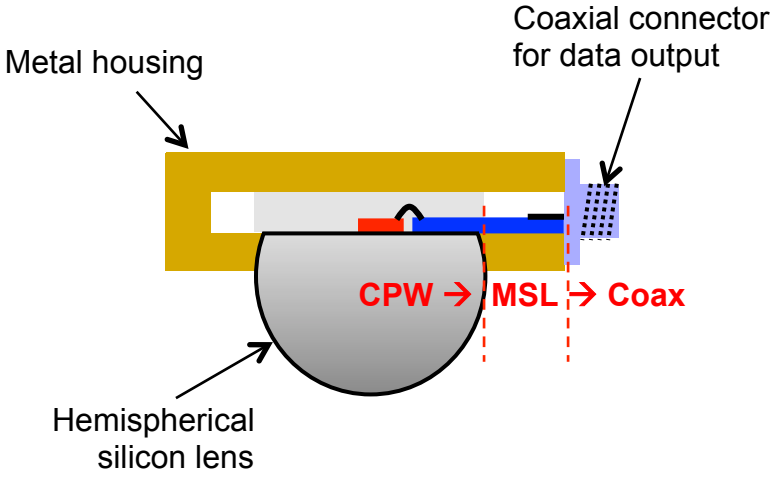


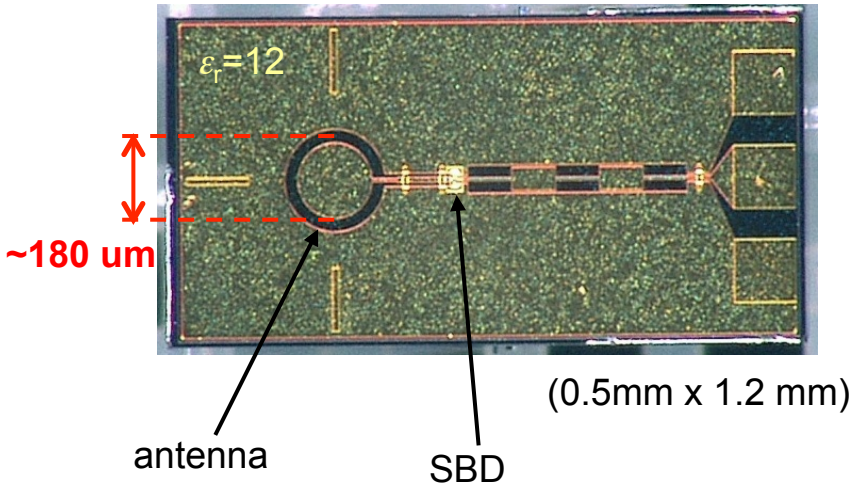


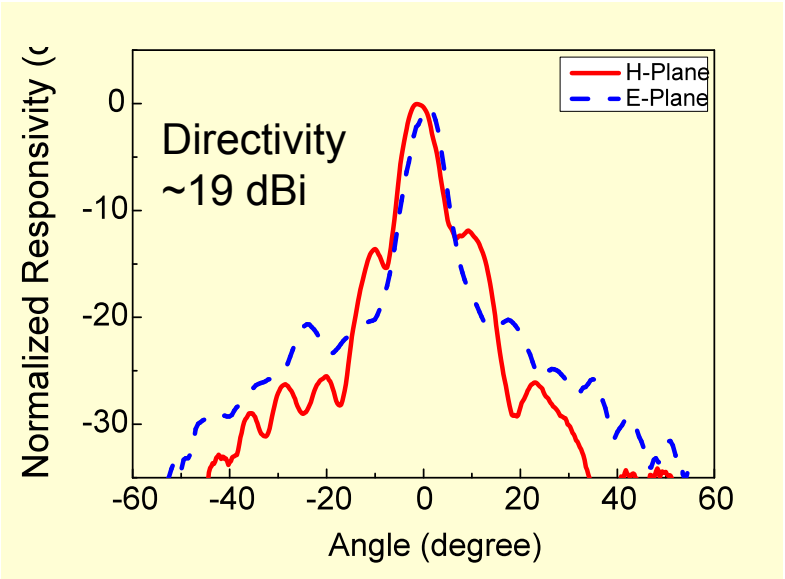
- New device provides much wider video bandwidth of around 17 GHz (cf. old ~ 4.5 GHz)
- Designed for 300 GHz operation with advanced SBD devices

NEW Schottky Barrier Diode Detector

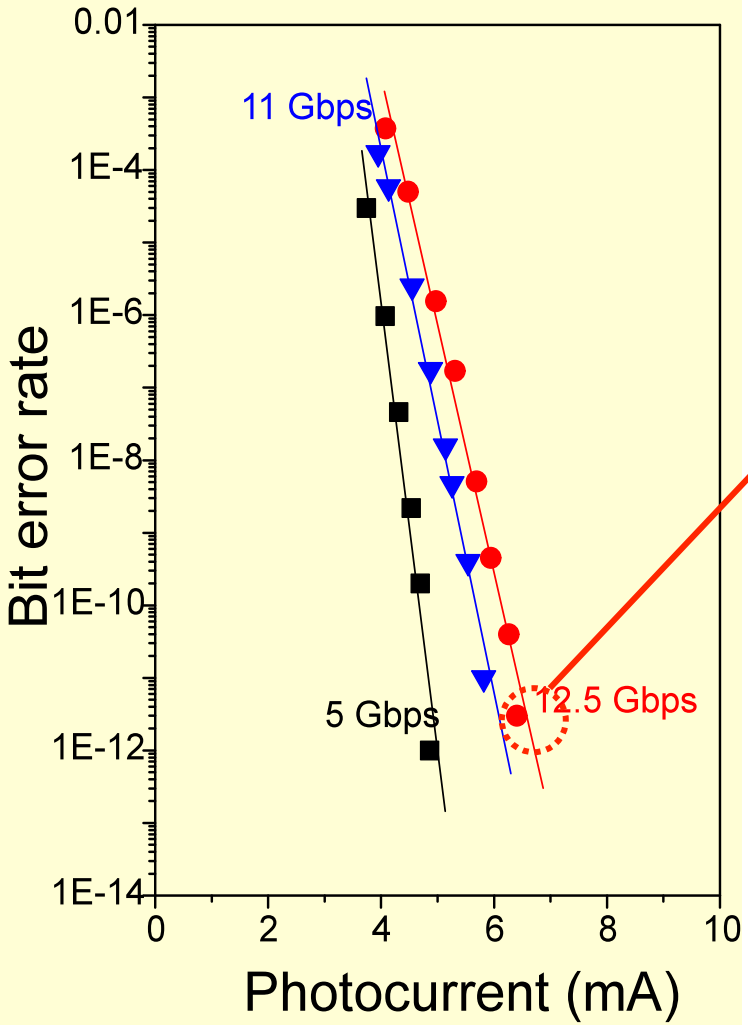




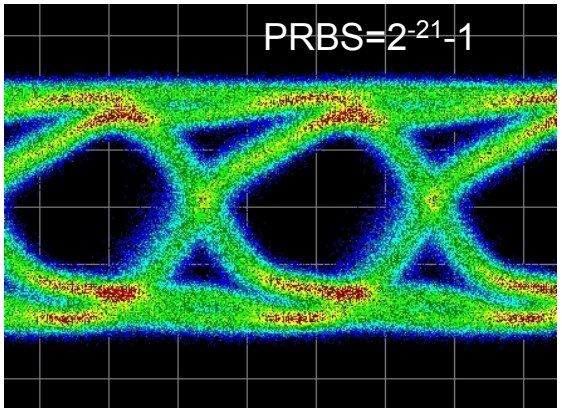




New Result with New Receiver



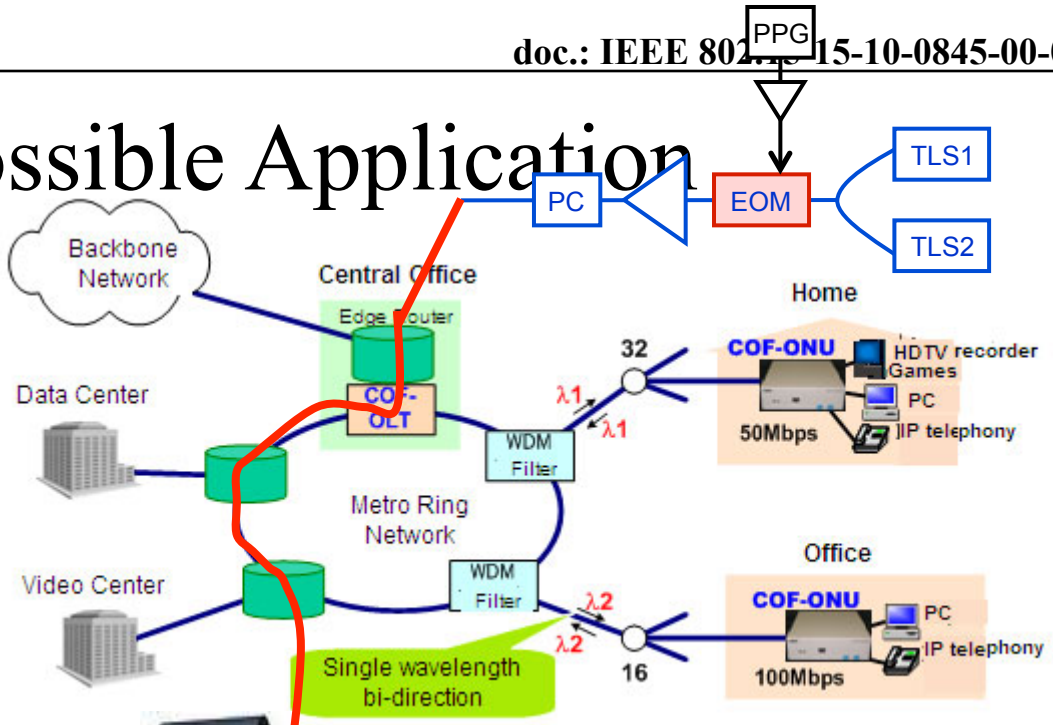
12.5Gbps



- We still have some power margin from UTC-PD
- 12.5 Gbps was limited by measurement setup (BERT)

Microwave Photonics 2010, WE3-2

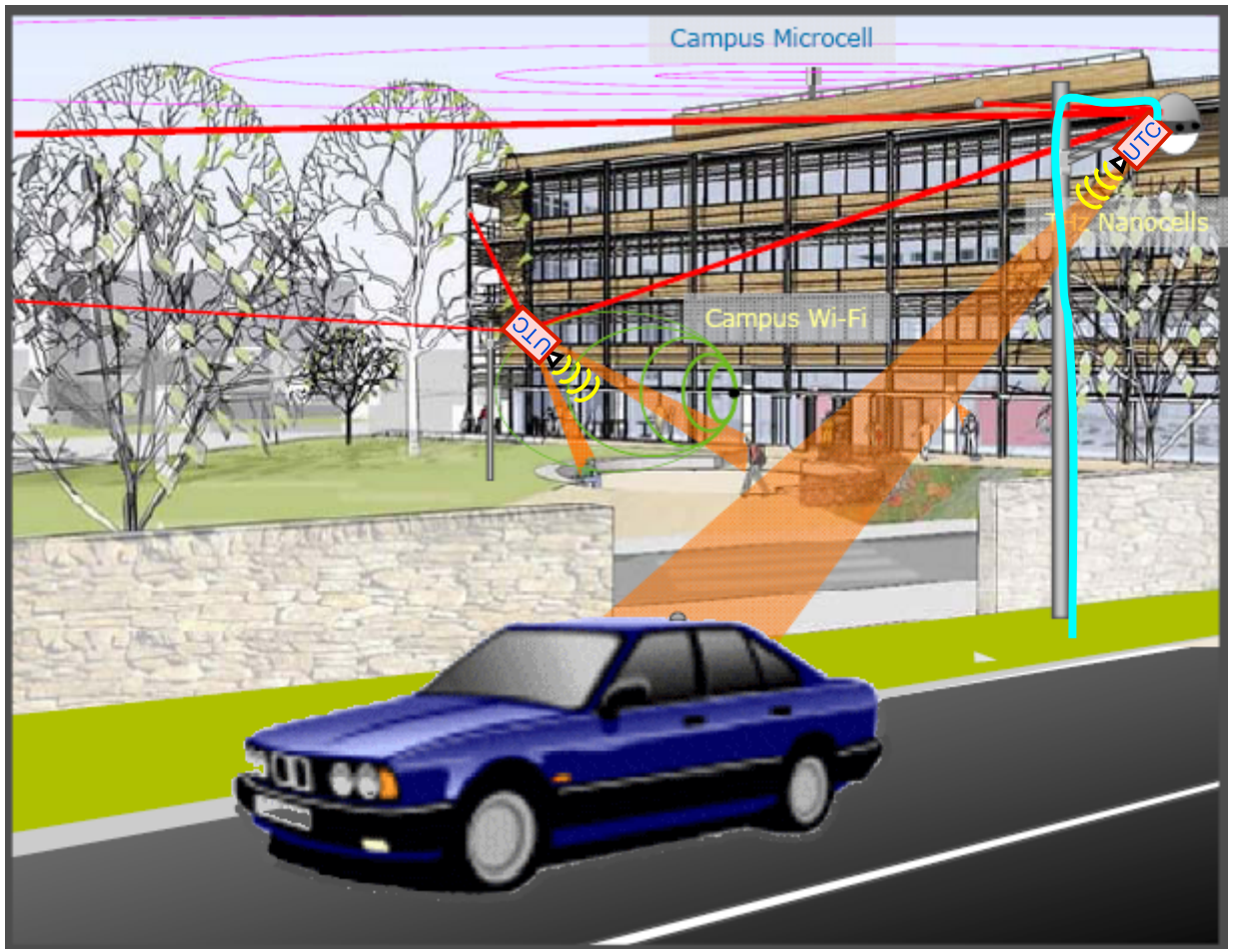
Possible Application



KIOSK data download
Via fiber-network

In Cabin link

Why Not ?!



IEEE 802.15-15-10-0150-00-0thz, Dr. Britz, AT&T

Issues in THz communications

- Frequency allocation: We need a lot

- High performance devices, especially for mobile unit.
- Packaging materials for practical application
- Channel characterization / modeling
- Beamforming, due to Line-of-sight (LOS) operation

Summary

- We demonstrated terahertz-wave wireless link at 300 GHz for feasibility test
  - Photonic transmitter + Schottky barrier diode detector receiver
  - 12.5 Gbps error free transmission over 0.5-m distance
- Note that all the results were due to the utilization of huge bandwidth at terahertz frequencies.
  - We didn't use so much high power (< 60 uW)
  - Noise performance of receiver was much worse than calculation.
  - But, we had **BANDWIDTH**.